Comparison of SVM & SPWM Technique for Three Phase Inverter

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Abstract: *Photovoltaic (PV) energy is the major renewable energy resource. It is necessary to convert direct current into alternating current in order to generate the electrical energy from this resource. Many of the presently available three-phase inverters with two-level mechanism gives the harmonics that cause distortions in the waveforms and affect the load connected to the circuit. To control the switching process of switching semiconductor devices, Pulse Width Modulation Techniques are implemented. There are many Pulse Width Modulation (PWM) techniques utilized in industrial requirements which require high end performance. There are many PWM techniques being implemented out of which, Space Vector Pulse Width Modulation (SVPWM) is prominent. Among other techniques, Space Vector Pulse Width Modulation (SVPWM) provides minimum Total Harmonic Distortion (THD) and acceptable results. The proposed work is simulated using one of the virtual simulating platforms, like MATLAB/Simulink software and the results obtained are discussed briefly.*

Keywords: **Three phase Inverter, Space Vector PWM Technique, Total Harmonic Distortion.**

1. INTRODUCTION

Converting the dc input voltage into ac output voltage is the basic principle of an inverter. By using proper controlling technique for the switches of inverter, A desired output voltage can be obtained. This is normally attained by using Pulse Width Modulation (PWM) techniques. The major four types of PWM techniques which are generally used for three-phase inverters are Sinusoidal PWM (SPWM), Third-Harmonic Injected PWM (THPWM), Sixty Degree PWM (SDPWM), and Space Vector PWM (SVPWM). Sinusoidal Pulse Width Modulation (SPWM) is used more frequently in many industries. Its easy implementation made it to use in industries. Both SPWM and Third Harmonic PWM give good performance in industrial application. Sampling frequency is varied to examine the effect of THD for both SPWM and THPWM. From simulation studies, it can be seen that that THPWM offers better performance than SPWM. Different modulation techniques like SPWM, Trapezoidal PWM, SDPWM and THPWM are analyzed by varying modulation index and switching frequency. THPWM offers 3.99% THD when modulation index 1 and switching frequency 20 kHz. The effect of sampling frequency is not considered in the analysis. THPWM shows reduced Total Harmonic Distortion compared to SPWM. Again, SVPWM offers lowest THD with greater performance than other techniques with better flexible output.

2. METHODOLOGY

The VSI uses the DC voltage source to produce the AC output. Here the DC voltage is converted to three phase AC output as the used model uses a three-phase inverter circuit.

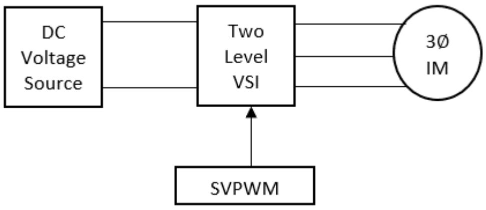


Figure 1: Block Diagram

The give block diagram represents the major components involved in working of a three-phase inverter to control the input supply to a three-phase induction motor.

2.1. DC Voltage Source:

The DC voltage source is connected, which provides input DC supply where the inverter generates the three-phase supply to induction motor. The voltage amplitude is provided as 400V. In hardware, boost converter is used to step up the voltage from battery or rectifier associated with auto transformer.

2.2. Three Phase Inverter:

For a three-phase inverter, three single-phase inverter arms are connected as shown in Figure 2.

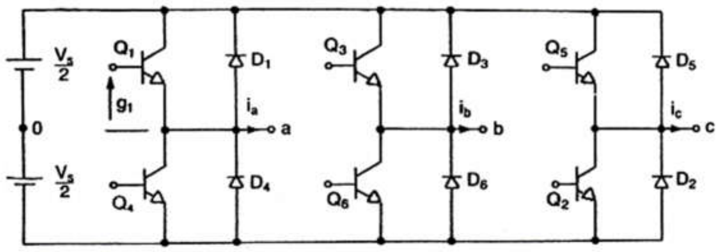


Figure 2: Circuit diagram for Three-Phase Inverter

Based on the control signal used, there are two types of conductions:

1. 120° conduction.
2. 180° conduction.

For the present work 180degree conduction mode is used. Where each switch will be turned on for 180degree interval when the gate pulse is applied.

2.3. Space Vector Pulse Width Modulation:

The SVPWM technique is applied to the three-phase inverter to produce the gate signals to control the switches. By using the SVPWM technique it is possible to increase the fundamental component by up to 27.39% that of SPWM.

The accomplishment of SVPWM is by moving a reference vector for 360degree to complete a cycle, in the state diagram, where six active vectors forming a hexagon. A circle inscribed inside the state diagram can represent the sinusoidal ac function. The area of the circle which is inscribed is called the linear modulation region or under-modulation region.

For a three-phase frame of reference, the equations are given as:

$$V_a = V_m \sin(\omega t) \quad (1)$$
$$V_b = V_m \sin\left(\omega t - \frac{2\pi}{3}\right) \quad (2)$$
$$V_c = V_m \sin\left(\omega t - \frac{4\pi}{3}\right) \quad (3)$$

These equations can be represented in the *dq* frame of reference. Where the resultant vector can be rotated in circular pattern to generate the necessary output.

Voltage Vectors	Switching Vectors			Line to Neutral Voltage			Line to line Voltage		
	a	b	c	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

Figure 3: Switching States for SVPWM

The switching states are given in the Figure 3. and are represented in the Figure 4. There are six active vectors at the corners of the hexagon with two zero vectors at the center of the polygon(hexagon). There are six sectors where four vectors for each sector included. Among four vectors two are active and other two are zero vectors. Each sector is separated at an angle of 60 degrees.

Under SVPWM technique, it is necessary to rotate the reference vector Vs in circular manner to generate the pure sinusoidal waveform output.

2.4. Equations:

In order to achieve the Space Vector PWM technique following equations are important.

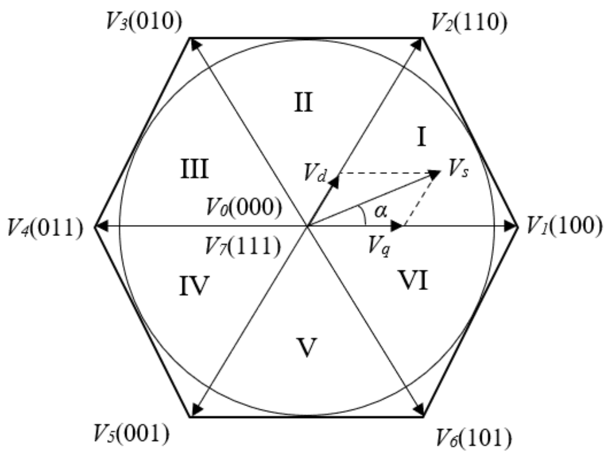


Figure 4: State map representation of vectors

To determine vectors V_d, V_q and V_s and angle α

$$V_d = V_{an} - V_{bn}\cos(60^0) - V_{cn}\cos(60^0) \quad (4)$$

$$V_d = V_{an} - \frac{V_{bn}}{2} - \frac{V_{cn}}{2} \quad (5)$$

$$V_q = 0 + V_{bn}\,cos(30^0) - V_{cn}\,cos(30^0) \quad (6)$$

$$V_q = \frac{\sqrt{3}V_{bn}}{2} - \frac{\sqrt{3}V_{cn}}{2} \quad (7)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (8)$$

$$|\bar{V}_{ref}| = \sqrt{V_d^2 + V_q^2} \quad (9)$$

$$\alpha = tan^{-1}\left(\frac{V_d}{V_q}\right) = \omega t = 2\pi f t \quad (10)$$

Estimating the time intervals, Tz_1, Tz_2 and Tz_0.

$$\int_0^{T_z} \bar{V}_{ref} = \int_0^{T_{z1}} \bar{V}_1\, dt \int_{T_{z1}}^{T_{z1}+T_{z2}} \bar{V}_2\, dt + \int_{T_{z1}+T_{z2}}^{T_z} \bar{V}_0 \quad (11)$$

$$T_z \cdot \bar{V}_{ref} = (T_{z1}\bar{V}_1 + T_{z2}\bar{V}_2) \quad (12)$$

$$T_z \cdot |\bar{V}_{ref}| \cdot \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix} = T_{z1} \cdot \frac{2}{3} V_{dc}\begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_{z2} \cdot \frac{2}{3} \cdot V_{dc}\begin{bmatrix} \cos\frac{\pi}{3} \\ \sin\frac{\pi}{3} \end{bmatrix} \quad (13)$$

$$T_{z1} = T_z\alpha \cdot \frac{\sin\left(\frac{\pi}{3} - \alpha\right)}{\sin\left(\frac{\pi}{3}\right)} \quad (14)$$

$$T_{z2} = T_z\alpha \cdot \frac{\sin(\alpha)}{\sin\left(\frac{\pi}{3}\right)} \quad (15)$$

Where, $T_z = \frac{1}{f_z}$ and $\alpha = \frac{\bar{V}_{ref}}{\frac{2}{3}V_{dc}}$

$$T_{z0} = T_z - (T_{z1} + T_{z2}) \quad (16)$$

Finally tabulating the ON time for each switch

Table 1. Switch ON Time for Each Switches

Sector	Upper Switches (Q_1, Q_3, Q_5)	Lower Switches (Q_4, Q_6, Q_2)
1	$Q_1 = Tz_1 + Tz_2 + Tz_0/2$ $Q_3 = Tz_2 + Tz_0/2$ $Q_5 = Tz_0/2$	$Q_4 = Tz_0/2$ $Q_6 = Tz_2 + Tz_0/2$ $Q_2 = Tz_1 + Tz_2 + Tz_0/2$

2	$Q_1 = Tz_2 + Tz_0/2$ $Q_3 = Tz_1 + Tz_2 + Tz_0/2$ $Q_5 = Tz_0/2$	$Q_4 = Tz_2 + Tz_0/2$ $Q_6 = Tz_0/2$ $Q_2 = Tz_1 + Tz_2 + Tz_0/2$
3	$Q_1 = Tz_0/2$ $Q_3 = Tz_1 + Tz_2 + Tz_0/2$ $Q_5 = Tz_2 + Tz_0/2$	$Q_4 = Tz_1 + Tz_2 + Tz_0/2$ $Q_6 = Tz_0/2$ $Q_2 = Tz_2 + Tz_0/2$
4	$Q_1 = Tz_0/2$ $Q_3 = Tz_2 + Tz_0/2$ $Q_5 = Tz_1 + Tz_2 + Tz_0/2$	$Q_4 = Tz_1 + Tz_2 + Tz_0/2$ $Q_6 = Tz_2 + Tz_0/2$ $Q_2 = Tz_0/2$
5	$Q_1 = Tz_2 + Tz_0/2$ $Q_3 = Tz_0/2$ $Q_5 = Tz_1 + Tz_2 + Tz_0/2$	$Q_4 = Tz_2 + Tz_0/2$ $Q_6 = Tz_1 + Tz_2 + Tz_0/2$ $Q_2 = Tz_0/2$
6	$Q_1 = Tz_1 + Tz_2 + Tz_0/2$ $Q_3 = Tz_0/2$ $Q_5 = Tz_2 + Tz_0/2$	$Q_4 = Tz_0/2$ $Q_6 = Tz_1 + Tz_2 + Tz_0/2$ $Q_2 = Tz_2 + Tz_0/2$

3. SIMULATION AND RESULTS

The simulation circuit with SPWM switching technique is provided in Figure 5:

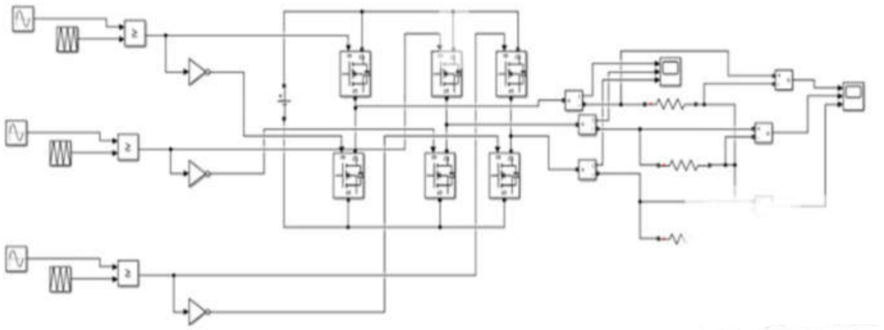
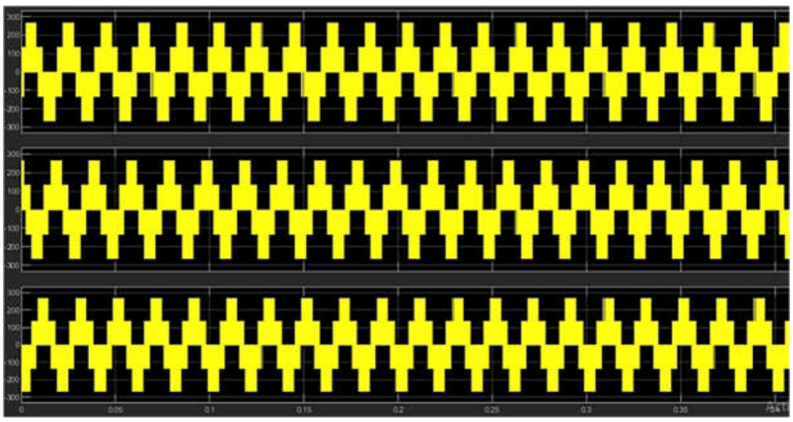


Figure 5: Simulation model for Sinusoidal Pulse Width Modulation Technique



y-axis: Voltage(V) x-axis: time(sec)

Figure 6: Output Waveforms for Sinusoidal Pulse width modulation

The dc voltage source of 400V is connected to the three-phase load through the inverter. The SPWM technique is used for generating the pulses which is provided to inverter. The load voltage waveforms are provided in the Figure 6.

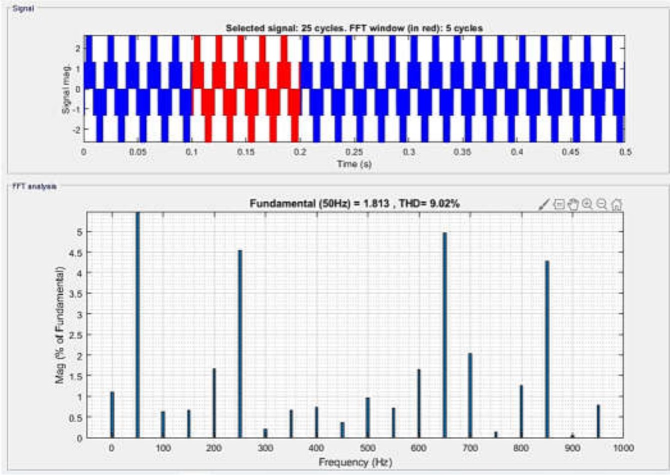


Figure 7: Total Harmonic Distortion for Sinusoidal Pulse Width Modulation

The %THD of the load voltage for SPWM technique is provided in Figure 7. The %THD is around 9.02% for the voltage waveforms with SPWM technique

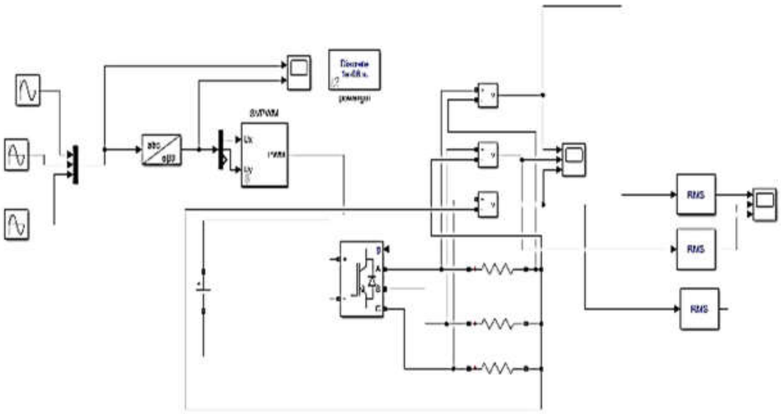


Figure 8: Simulation model for Space Vector Pulse Width Modulation

Now the switching technique is changed to SVPWM technique with switching frequency as 2KHz and modulation index as 1. The simulation circuit for three-phase inverter with SVPWM technique is provided in Figure 8.

The simulation is based on the basic working principle of an inverter where the DC input is converted to AC output. Input for the control circuit is given by connecting three single phase refence signals each are specified for the phase angle varied by 120 degrees. These three signals are added up by using a MUX block.

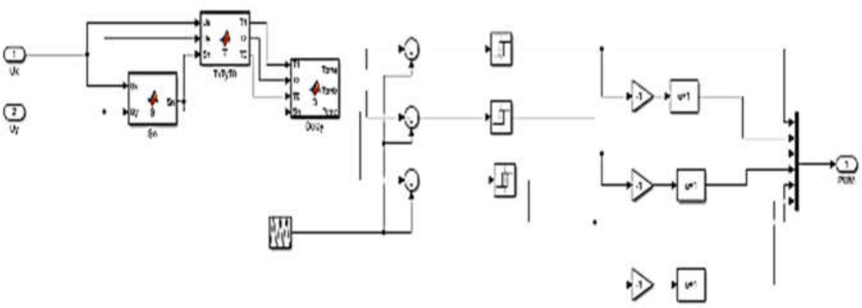
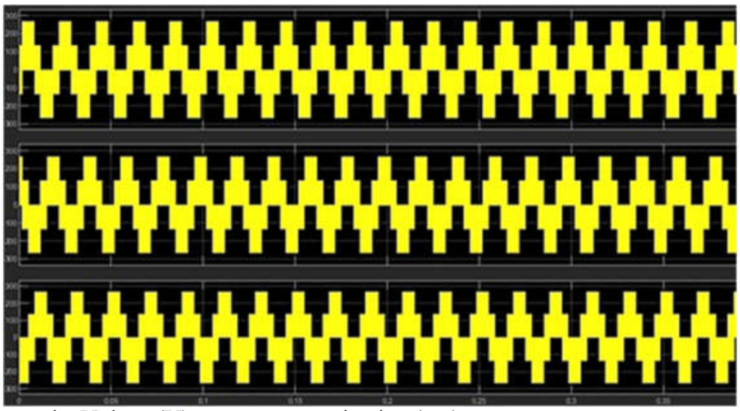


Figure 9: Control circuit Simulation model for Space Vector Pulse Width Modulation

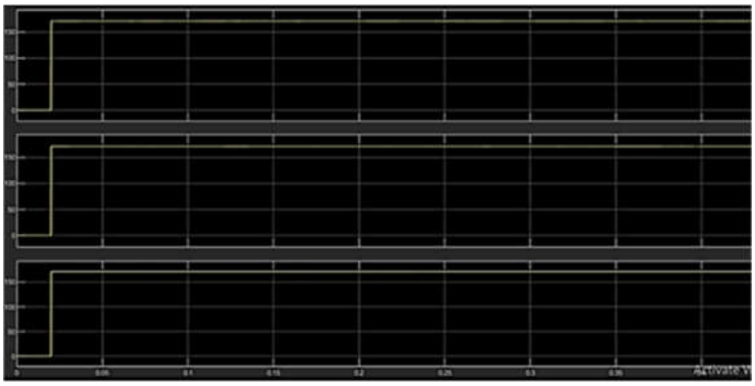
It is necessary to represent the three-phase signal in terms of two vector reference. The three-phase signal is then converted to an alpha-beta-zero stationary reference frame by using a suitable block from the Simulink library. This reference frame is then taken as two signals to generate the gate pulses and to specify time periods



y-axis: Voltage(V) x-axis: time(sec)

Fig 10: Three phase Output generated at the end of Simulation of Space Vector Pulse Width Modulation

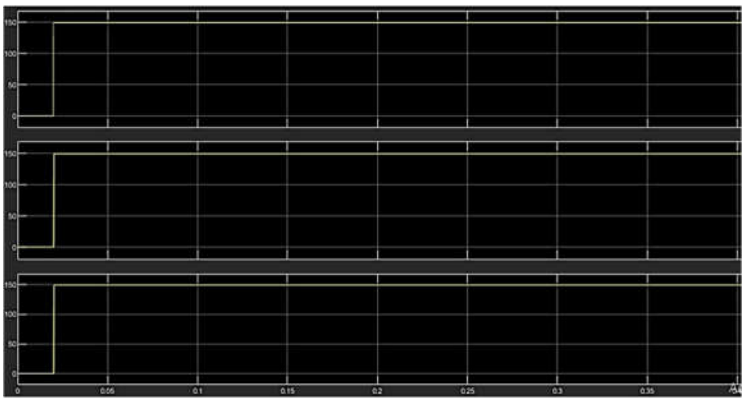
The voltage reference waveforms for three phases are created with the help of sine function block and provided for Clarke transformation. The transformed voltages are provided for SVPWM block which generates the pulses for the inverter. The three phase load voltage waveforms are provided in Figure 10.



y-axis: Voltage(V) x-axis: time(sec)

Fig 11: The rms waveforms for the load voltages of modulation index 1.

The rms voltage value for the load voltage for modulation index of 1 is provided in Figure 11.



y-axis: Voltage(V) x-axis: time(sec)

Fig 12: The rms waveforms for the load voltages for modulation index 0.5

The rms value of the load voltage for modulation index, m=1 is around 175V. When the modulation index is varied, the rms voltage also varies accordingly. The rms value of load voltage for m=0.5 is provided in Figure 12.

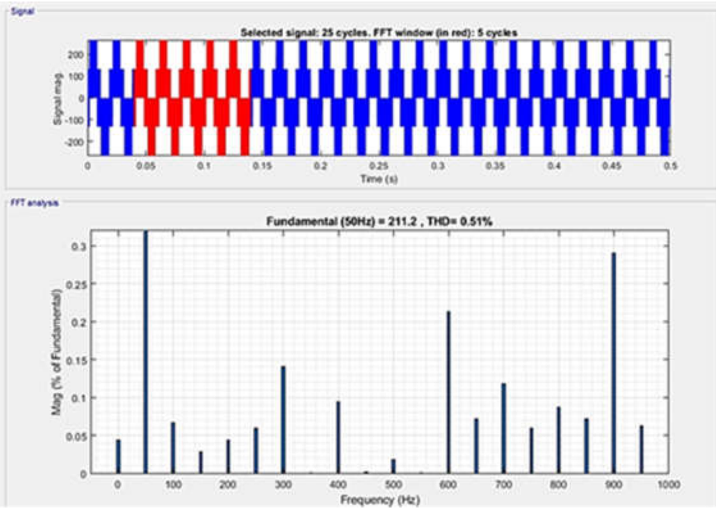


Fig 13: Total Harmonic Distortion for Modulation Index 0.5

For m=0.5, the rms load voltage is around 150V. The %THD for the load voltage with switching frequency fs=2KHz is provided in Figure 13.

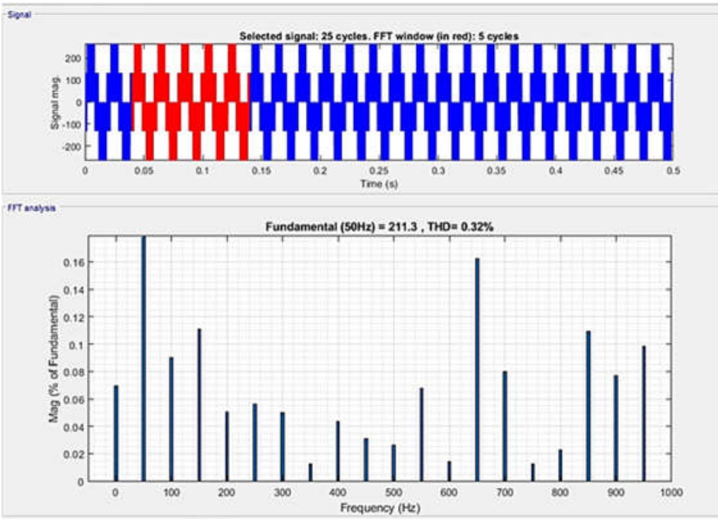


Fig 14: Percentage Total Harmonic Distortion for sampling frequency 5kHz

The %THD for load voltage is around 0.51% for Fs=2KHz. When the switching frequency is increased to 5KHz, the %THD is reduced as provided in Figure 14. The %THD for load voltage is around 0.32% for Fs=5KHz.

4. CONCLUSION

It is observed that, by comparing the SPWM and SVPWM techniques for different modulation index and at different sampling frequencies, SVPWM provides the better-quality output. With minimised THD, the quality of the output can be maintained within the tolerance values. The simulation of both SPWM and SVPWM controlling techniques gave a proper insight on the reduction in THD.

Solar energy being major renewable energy source, Inverters play a predominant role in the generation of electrical power. Lower THD can provide a quality power generation from the solar panels. The quality of the power supplied to the consumers and electrical utilities should adhere to the stringent norms prescribed for the power quality.

5. REFERENCE

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